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Residential Energy Conservation and Price Response

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RESIDENTIAL ENERGY CONSERVATION AND PRICE RESPONSE. Margo Rich Ogus, Economic Development Division, Economic Research Service, U.S. Department of Agriculture, Washington, D.C. March 1982. ERS Staff Report No. AGES820216.

ABSTRACT

This paper examines the factors affecting the quantity of home heating fuel used and compares the willingness of consumers of natural gas (NG) and liquified petroleum gas (LPG) to adjust to very different changes in their heating costs over similar periods of time. LPG households made more and bigger temporary changes than did NG households and were more persistent in maintaining their behavior. LPG households also made structural improvements to the heat resistance of their homes while few NG households did so. Although people can adjust their fuel-use habits, a substantial economic incentive is required to create a significant and sustained response.

Keywords: residential energy consumption, energy prices, energy consumption

AUTHORS NOTE

This work was completed in conjunction with the author's doctoral dissertation research at Stanford University and was funded by the U.S. Department of Agriculture. The author is currently employed in the Economics Policy Research Department of the Bank of America.

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HIGHLIGHTS

This study examined the roles of various factors in determining the residential fuel consumption of a sample of liquified petroleum gas (LPG) households and natural gas (NG) households in rural Indiana. LPG-fueled households faced traditionally higher gas prices.

The study also compared the responsiveness of these consumers to different changes in their heating costs. LPG households increased fuel use efficiency some 10.3 percent in the 1973/74 winter when LPG prices doubled. They maintained and improved the increase in the following years.

NG households increased their efficiency 7.8 percent in 1973/74. However, this was not statistically significant nor was it maintained over time.

The survey suggests that people are willing to adjust their fuel-use habits through the adoption of energy-saving measures in both the short and long run. However, a substantial economic incentive is required to create and sustain a significant response.

Fuel use by NG households was increased by more doors and stories in the house and presence of a heated basement. The number of adults in the home and the presence of a hot water heater or dryer also increased fuel consumption. Wall insulation, storm doors, and the presence of a porch reduced energy consumption.

For LPG households, fuel use increased with size of household, number of stories, presence of a basement or garage which enlarged the total heating area as well as presence of a fireplace, LPG fueled hot water heater and dryer. Attic and wall insulation and storm doors were important energy conservers.

NG households did not experience large price increases during the period covered by the study. Without a price incentive they did not adopt conservation measures.

LPG households responded to the surge in their fuel prices by implementing low-cost measures immediately, such as lowering thermostat settings. Over the following years they made more permanent energy-saving improvements to their homes such as attic and wall insulation.

RESIDENTIAL ENERGY CONSERVATION AND PRICE RESPONSE

Margo Rich Ogus*

INTRODUCTION

Household consumption of energy in all forms is one of the principle determinants of total energy use in the United States. As energy conservation has become a national priority, households have been urged to adopt various conservation practices. There is considerable disagreement about whether people are willing or are able to adjust their fuel use habits to any great extent.

Some economists believe household response is severely limited by the inability of consumers to alter their fuel use, especially in the short run. They suggest that consumers are "locked-in" to a set of appliance and heating systems they did not choose or chose in an era of significantly different relative fuel prices. A 1974 study by the Federal Energy Administration notes that "decisions on...products and materials used in most new residential...structures are made...by the developer (whose)...primary concern, frequently, is to...minimize the initial cost of the energy system, because...he will not be paying the energy costs". 2/

The implication is that a large capital investment, the gradual introduction of a more efficient capital stock, is critical to the process of energy conservation. Consequently, many energy demand studies focus solely on changes in the appliance stock. Others argue that consumers are unwilling to conserve energy, as energy costs account for too little of a middle-income American's budget to cause a real pinch as prices increase.

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*This work was completed in conjunction with the author's doctoral dissertation research at Stanford University and was funded by the U.S. Department of Agriculture. 1/ The author is currently an economist in the Commodity and Industry Analysis section, Economics-Policy Research Department at the Bank of America.

1/ Rich, Margo Beth, "Residential Energy Conservation and Price Response", Ph.D. Dissertation, Food Research Institute, Stanford University, Stanford, California, 1980.

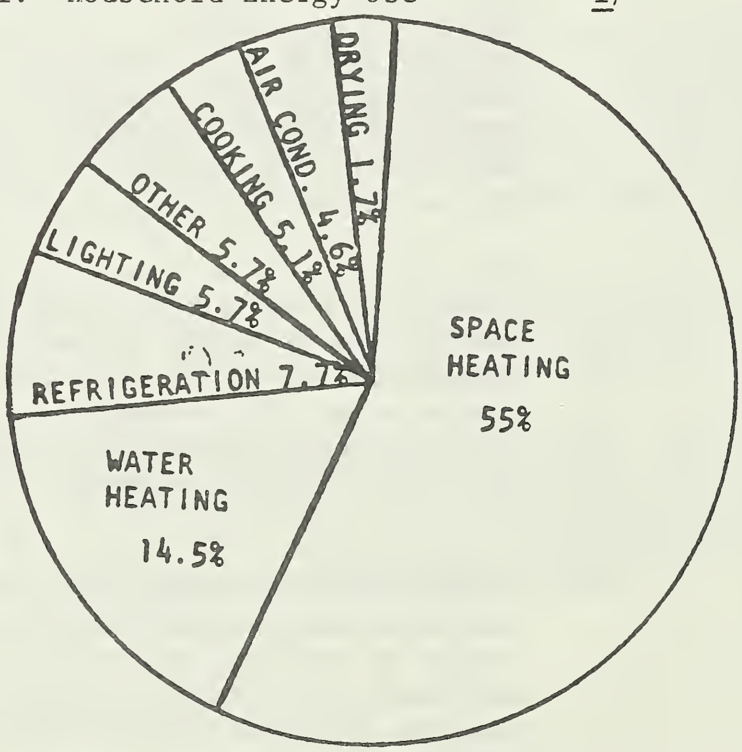
2/ United States. Federal Energy Administration, Residential and Commercial Energy Use Patterns 1970-1990, Project Independence Blueprint, Final Task Force Report, Volume 1, 1974.

Clearly, if energy prices have been too low, historically, to motivate the adoption of conservation measures, the incentives to improve fuel-use efficiency have been reinforced by the recent increase in the real prices for fuels.

The objective of this paper is to isolate and measure the factors affecting the quantity of heating fuel used in the home and to compare the extent to which consumers of two different fuels (natural gas and liquefied petroleum gas) have adjusted to increases in the price of their energy. Unfortunately, given the cross-sectional nature of the data, there was no variation in fuel prices paid by households within each of the two fuel groups considered. As a result, the direct estimation of fuel price elasticities is not addressed. The study does, however, look at differences in the actual adjustments made by the two sets of households to reduce their fuel use and in their appliance inventories in an attempt to assess their price responsiveness. Attention in this study focuses upon energy used for home heating.

Energy use in the United States totalled 75.7 quadrillion (10^{15}) British thermal units (BTU's) in 1977 or an average of 350 million BTU's per person. 3/ Households use about one-fifth of this total, 40 percent of which comes from natural gas and 35 percent from electricity. The next largest source of energy

Figure 1: Household Energy Use 1/



1/ Dole, Stephen, Energy Use and Conservation in the Residential Sector: A Regional Analysis, Rand Corporation: R-1641-NSF, Santa Monica, California, 1975.

3/ Cohn, Steve, Eric Hirst and Jerry Jackson, "Econometric Analysis of Household Fuel Demands: Oak Ridge National Laboratory: ORNL/CON-7, 1977.

to the home is fuel oil (18 percent). Figure 1 diagrams the distribution of primary residential energy consumption in the United States in 1970. Space heating is by far the largest user of energy in the home.

Between 1950 and 1975 the overall annual growth rate of residential energy use was 3.4 percent -- almost 1 1/2 times the rate of household formation (2 percent). 3/ The higher growth rate in energy consumption was primarily due to two factors: the increasing proportion of households that had major appliances, and the increasing energy requirements of each appliance, often due to increased capacity and added features which require additional power. Appliances which have been available for a long time (for example, refrigerators and washing machines) are now in nearly all homes while the proportion of households having high energy-use major appliances introduced after World War II has been increasing steadily. 4/ 5/ The average annual growth rate of 6.1 percent for natural gas use between 1950 and 1975 was due to the purchase of NG-fueled appliances, both original and replacement, and was compounded by the increased availability of NG hookups, which made possible the construction of new NG-fueled homes. As of late 1979, natural gas continues to be an inexpensive source of energy relative to its alternatives.

DATA DESCRIPTION

In the spring of 1976, a survey of households in rural Indiana was completed. The sample contained 90 houses fueled by natural gas (NG) and 129 users of liquefied petroleum gas (LPG), thus making possible a comparison of the behavior of the two sets of households who faced significantly different fuel prices. Actual fuel use records (price and quantity) were obtained from the local fuel suppliers. Households were surveyed by mail and asked to provide specific information about the physical characteristics of their houses and socioeconomic data about their families. Households indicated the presence or absence of major appliances that used either type of gas.

The survey also asked about the types of changes that the households had made in their fuel use habits from 1971 to 1976. Three types of changes can be distinguished. The first type affects the actual transformation of fuel to heat. The second type are structural adjustments, changes in the heat retention properties of the house. The third type are changes in the stock or of utilization of the major appliances recorded. Some of these changes require only an adjustment in habits and incur no expense. Others are more permanent and generally require the expenditure of time or money. Finally, the data cover an

4/ Newman, Dorothy and Dawn Day, The American Energy Consumer, Energy Policy Project of the Ford Foundation, Cambridge, Mass: Ballinger, 1975.

5/ Tansil, John and John Moyers, "Residential Demand for Electricity" in Energy: Demand, Conservation and Institutional Problems, Michael Marcrakis, Editor, Cambridge, Mass: MIT Press, 1974.

especially interesting time period 1971/72 to 1976/77, when the price changes for the two fuels were very different. 6/

While the markets for LPG and natural gas are generally different due to the locations of NG pipelines, attempts were made to minimize any effects of these market differences. Natural gas pipelines tend to be located in areas with fairly large population in order to justify main line service. However, rural communities located near a natural gas transmission line can often gain access to the line via the installation of a feeder line. Of the households surveyed, those with access to such a feeder line used NG for heating, while those households living in the surrounding areas, but too far from the feeder line, heated with LPG. While it is not possible in this report to discuss in detail the responses made to the survey questions, it is clear that differences in energy efficiency are not due to inherent physical factors. 7/ The physical characteristics of these two sets of households are in fact quite similar. The households live in the same area and the original construction decisions, likely to have been made by the developer, appear to have been influenced by factors other than the type of fuel that would be available to the future home buyers.

The data permit a direct estimation of fuel use efficiency for each household. When the consumption figures are weighted by the accumulated heating degree days recorded for this part of Indiana, a measure of fuel-use efficiency, K, by household, can be calculated for each year. 8/ K is defined as the number of heating degree days overcome by one gallon of LPG or its heating equivalent for NG. The prices confronted by these families and their average fuel-use adjustments over the five year period are summarized in figure 2 and table 1.

As shown in figure 2, the price per BTU of LPG, a private-market fuel, was more than twice that of the federally regulated natural gas in 1971. During the winter of 1973/74, LPG prices nearly doubled while the price of NG changed only marginally. While LPG prices declined some from this peak, they remained 70 percent higher than their pre-1973 levels. NG prices grew slowly, actually declining in real terms, until 1975 when prices jumped 25 percent. Even with this price hike, however, LPG prices remained over twice as high as NG prices.

Few of the changes in fuel-use efficiency were statistically significant (Table 1). Nevertheless, the pattern suggests that differences in price behavior are reflected in the aver-

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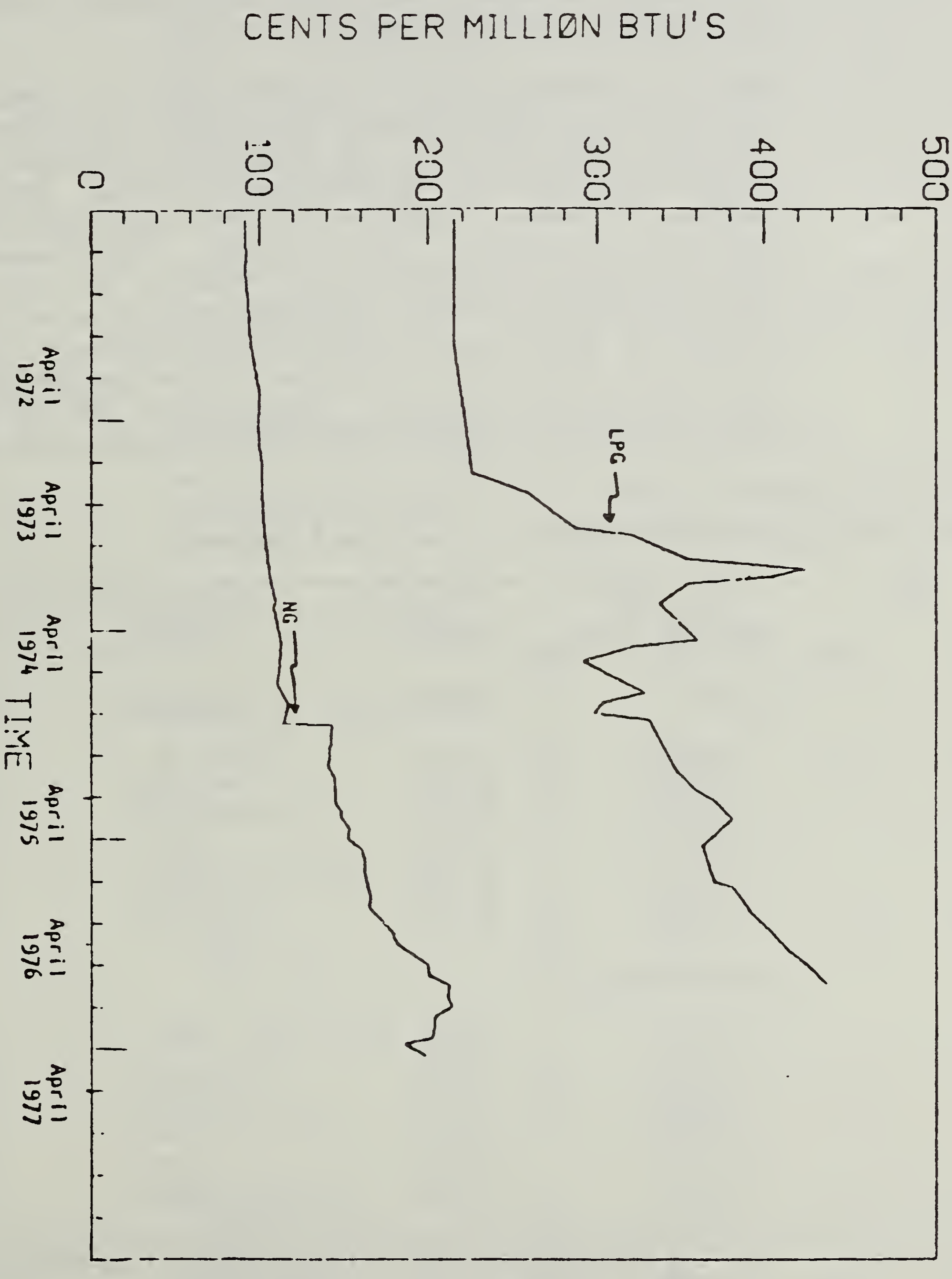
6/ The heating year runs from July 1 through June 30.

7/ A complete description of the data is available in publication cited in 1/.

8/ A heating degree day is accumulated for each degree below below 65°F to which the daily mean temperature falls. For example, if the daily mean temperature for a given day is 40°F, 25 heating degree days would be recorded for that day.

Figure 2: LP and Natural Gas Prices



age responses of the surveyed households. LPG households increased fuel-use efficiency some 10.3 percent in the 1973/74 winter over the previous year and maintained the improvement in the following years. While NG households increased their efficiency 7.8 percent in 1973/74, the change was not statistically significant. The subsequent large price increase in 1974/75, did little to change fuel-use efficiency of the NG households, although the NG shortage in 1975/76, compounded by the subsequent severe winter and the threat of shortage, did bring about some improvement.

While the survey queried households about the fuel conservation measures they adopted after 1973, these survey data also provide some indications of the kinds of adjustments of a much longer run nature that households have made. The efficiency measures in table 1 indicate that LPG users tend to be more efficient, on average, than NG users. These households also faced consistently higher prices than the NG users. This characteristically higher efficiency could be achieved in a variety of ways, such as having fewer appliances using gas because efficiency is a function of home heating and total fuel use, adjusted for weather. Comparison of LPG and NG households' survey responses suggests that characteristics of the housing

Table 1--Changes in Fuel-Use Efficiency

Major fuel Heating year	Average K factor 1/	Change in K value	T-test 2/
LP gas 3/	Number	Percent	Value
1971/72	4.415	NA	NA
1972/73	4.542	2.88	0.68
1973/74	5.012	10.35	2.25
1974/75	5.218	4.11	0.92
1975/76	5.400	3.49	0.77
1976/77	5.511	2.05	0.46
Natural gas 4/			
1971/72	3.844	NA	NA
1972/73	3.852	0.21	0.04
1973/74	4.152	7.79	1.49
1974/75	4.116	-0.87	0.17
1975/76	4.167	1.24	0.24
1976/77	4.329	3.89	0.75

1/ K equals degree days divided by fuel consumption.
2/ The t-test tests the hypothesis that the increase in average efficiency between years is significant. T greater that 1.645 indicates an increase that is significant at the five percent level.
3/ Based on 129 households.
4/ Based on 90 households.
NA = Data not applicable.

stock do not account for differences in long-run efficiency. Investigation of sources of the observed differences in fuel use efficiency, however, indicates that there are some differences in long-run responses.

For example, a similar proportion of the NG and LPG households indicated that their attics were insulated (86 and 91 percent, respectively). However, when the same households recorded the actual numbers of inches of insulation, LPG households clearly had much more protection. Sixty-two percent of the NG households with insulation had less than four inches, compared to 39 percent of the LPG households. Further, 17 percent of the LPG respondents had eight or more inches, while none of the NG households had more than seven inches. Similarly, 80 percent of the LPG households, compared with only 67 percent of NG households, responded that their homes had wall insulation.

Interesting evidence on appliances used by these households is also available. Table 2 summarizes the data on appliances owned and their fuel sources for the sample households. While

Table 2--Distribution of Appliances by Fuel

Appliance and Fuel	Sample households with appliances of specified fuel type			
	NG		LPG	
	No.	Pct.	No.	Pct.
Hot water heater				
Sample	83	100.0	118	100.0
Gas	68	81.9	77	65.2
Electric	15	18.1	41	34.7
Clothes dryer				
Sample	70	100.0	96	100.0
Gas	25	35.7	25	26.0
Electric	45	64.3	71	74.0
Air conditioner				
Sample	46	100.0	66	100.0
Gas	0	0.0	1	1.5
Electric	46	100.0	65	98.5
Refrigerator				
Sample	83	100.0	119	100.0
Gas	1	1.2	0	0.0
Electric	82	98.8	119	100.0
Stove				
Sample	82	100.0	120	100.0
Gas	67	81.7	76	63.3
Electric	15	18.3	44	36.7

ownership of major appliances is approximately the same among both sets of households, important differences exist in the choices of the two sets of households. For the three major appliances for which gas is an available and viable alternative to electricity -- stoves, water heaters, and clothes dryers -- LPG households have many more electric appliances than NG households. These choices reflect the fact that LPG households have always paid more for their fuel than NG households.

While the time frame of the survey is too short to record much long-run response it does suggest that consumers do make economically appropriate decisions, and that, in the long term, consumers do adjust their fuel using habits to the relative prices of energy alternatives. In the next section a theoretical framework is described for estimating whether the short and long-run responses to changes in energy prices and national campaigns to conserve are statistically important in explaining change in actual fuel use.

THE ANALYSIS

Theoretical Background

The traditional theory of consumer behavior is based on the the belief that households derive utility from the consumption of goods which are purchased in the market. Consumption behavior can primarily be explained by changes in real income and relative prices. Variations in taste explain any other observed behavior. The theory of the household production function, suggested by Becker and, independently, by Lancaster, departs from the traditonal theory by suggesting that the household is not merely a consumer. 9/ 10/ Rather than deriving utility directly from purchased goods, the household combines market goods as inputs in a production process to produce the commodities desired and from which utility is derived. Hence, the household is not just a passive consumer but an active producing unit, similar to that of a small factory. Also, like that of a firm for factors of production, the consumer's demand for market goods is a derived demand, since goods are desired solely as inputs into the production of commodities. This approach appears to be particularly suited to exploring the "demand" for goods such as natural gas or electricity which are not consumed directly but which are inputs into the "consumption" or use of a furnace and a host of appliances. As the household's demand for energy is a derived demand, the household production function approach will be used to estimate the residential demand for heating fuel.

In this analysis, the household is defined as the consuming unit whose preferences over the commodity space are assumed to be well-behaved. Consumer utility is derived from a set of commodities or services, Z_i, i=(1,...k), which are the

9/ Becker, Gary S., "A Theory of the Allocation of Time," Economic Journal, Volume LXXV, Number 299, 1965.
10/ Lancaster, K. "A New Approach to Consumer Theory," Journal of Political Economy, Volume LXXIV, Number 2, 1966.

arguments of a conventional utility function for the households. Thus, for each household,

$$U_j = g_j(Z_1,\ldots,Z_k) \qquad (1)$$

In addition, each Z_l is the output of a household specific production process

$$Z_l = h_j(x_1,\ldots,x_n) \qquad (2)$$

which converts the inputs (x_i's) -- market goods, and in some cases, time -- into the desired outputs. The consumer is viewed as demanding, among other commodities, an adequately heated home, which we'll call Z_1.

Heating fuel is the primary market input in residential space heating. Its transformation to heat is governed by numerous technical relationships. According to engineers the amount of heat required to maintain a chosen indoor temperature depends on various structural characteristics of the particular house, including the size of the house, the type of siding and windows and the levels of insulation in the attic, walls, and floors. 11/ These variables provide production-like substitution possibilities to fuel use in home heating. Over time, alterations made in the fuel-heat transformation due either to changes in the desired level of heat or in the structural factors will cause a change in the level of fuel needed. The production function can be written as:

$$Z_1 = a_1 + a_2F_i + a_3W + a_4S + a_5R + a_6Fl + a_7D + a_8I \qquad (3)$$

where:

Z_1 is the quantity of home heating consumed, F is fuel consumption and the following are categories of non-market shifters which describe heating requirements of different parts of the house. 12/

W is heat loss through the windows,

S is heat loss thorugh the walls,

R is heat loss through the roof,

Fl is heat loss through the floor,

11/ Leckie, J., G. Masters, H. Whitehouse, and L. Young, Other Homes and Garbage: Designs for Self-Sufficient Living, San Francisco: Sierra Club Books, 1975.

12/ The amount of heat required to maintain a pre-determined indoor temperature is computed as the sum of the areas of the six parts of the house, each multiplied by their U values. See (Leckie, et. al., 1975) for a complete explanation.

D is heat loss through the doors,

I is heat loss from air infiltration.

The household production function model for describing consumer behavior has a particular appeal, especially in the determination of household demand for fuels. As Pollak states, the household production function model "stresses the role of the household's technology as well as its tastes as a determinant of behavior". 13/

According to Lancaster, the transformation equation -- which he refers to as the consumption technology -- plays the central role in the household production function approach. Similarly to firms, households have access to alternative technologies which require varying amounts of fuel depending on the levels of structural variables which affect heat-loss properties of the house. The household chooses that mix of inputs which achieves the desired level of Z_1 for the lowest cost. As a result, the household production function model recognizes a greater degree of substitution in the demand for a commodity than does the traditional model.

Lancaster identified two different types of substitution effects. The first, consumption substitution, results when an increase in the price of the input, such as fuel, causes less Z_1 to be demanded as the household shifts to consumption of commodities using less of the now more expensive input. The second effect, called efficiency or production substitution, results when an increase in the price of an input causes a change in the least costly way of production Z_1. Opportunities for changes in the product technology -- substituting improved structural factors for fuel -- would diminish the impact on Z_1 of an increase in the price of fuel. The two effects are independent. However, the relative impact of each, when the price of an input changes, will depend on the existing production function, the opportunities for adopting new technology, and the proportion of the new costly input used in the production of the desired input.

In addition to the production constraint (2), the utility function is maximized subject to the budget constraint.

$$Y = \sum P_i x_i \qquad (4)$$

where Y is household income and the p_i's are the prices of

the x_i's. Maximizing utility for an individual household, j,

13/ Pollak, R. A. "Welfare Evaluation and the Cost-of-Living Index in the Household Production Model," American Economic Review, Volume 68, Number 3, 1978.

in the conventional way provides separate demand equations for each input. The demand for fuel, F, is expressed as:

$$F_j = a_1+a_2Fl_j+a_3W_j+a_4D_j+a_5S_j+a_6R_j+a_7I_j+a_8Y_j \qquad (5)$$

where

j = household

Y = household income

Since fuel is the only variable market input used in producing heat, in the short-run, the p_i's include only the prices of purchased and alternative heating fuels. 14/ Due to the cross-sectional nature of the data, there was no variation in fuel prices paid by households within each of the two fuel groups, and consequently, no price variable can be included. The absence of a price variable, however, may avoid the potential problem of simultaneity between fuel prices and the structural characteristics in these equations (although it was previously suggested that the structural variables are predetermined without a consideration of prices). The analysis assumes that the appropriate production function is linear. Engineers generally agree that, in the range of standard indoor temperatures, the fuel-to-heat transformation has a linear relationship. 15/ 16/

Recalling that the factors Fl, W, D, S, R, and I are actually descriptive categories of structural characteristics in a house, it is necessary to replace each of them with the actual variables which describe heat retention. The fuel demand equation for a given year is shown below.

$$\begin{aligned} K_j = {} & a + b_1ATTIC_j + b_2ATTICINS_j + b_3WINDOW_j \\ & + b_4CURTAINS_j + b_5SIDING_j + b_6WALLINS_j + \\ & b_7STORIES_j + b_8PORCH_j + b_9DOORS_j + \\ & b_{10}DOORPROT_j + b_{11}BASEMT_j + b_{12}FLOOR_j \\ & + b_{13}SIZE_j + b_{14}FIREPL_j + b_{15}GARAGE_j \\ & + b_{16}AGE_j + b_{17}PEOPLE_j + b_{18}CHILDRN_j \end{aligned}$$

14/ There is no problem with a block rate pricing structure, as the fuels in question have a sufficiently large residential "block" to encompass all uses for the fuel.

15/ Quentzel, David, "Night-Time Thermostat Setback: Fuel Savings in Residential Heating", ASHRAE Journal, Volume 18, Number 3, 1976.

16/ Seidel, M. R., "The Costs of Cold Weather and the Conservation of Residential Heating Gas," United States Federal Power Commission, 1977.

$$+ b_{19}HOMEDAY_j + b_{20}Y_j + b_{21}HWH_j +$$

$$b_{22}DRYER_j + b_{23}STOVE_j + e \qquad (6)$$

The a and b's are parameters and e is a stochastic error term. There are actually two possible dependent variables that could be used. The first possible dependent variable, K, was defined earlier as the number of heating degree days divided by total fuel and controls for the influence of weather. An alternative is to use actual fuel consumption, F, directly with weather as an explanatory variable. The first two variables represent heat loss through the ROOF (the presence of an attic (ATTIC) and the amount of attic insulation (ATTICINS)). The next two variables indicate heat loss through the WINDOWS. For each house, an R value was calculated for the windows (WINDOW). 17/ In addition, the presence or absence of (CURTAINS) was indicated.

Heat loss through the SIDES was represented by the following four variables: (SIDING) - an R value for the type of siding material; (WALLINS) - number of inches of wall insulation; (STORIES) - number of stories in a house; (PORCH) - presence or absence of an enclosed porch, which may act as a wall buffer. Two variables indicated heat loss through the DOORS. (DOORS) gives the total number of doors and (DOORPROT) is the percentage of doors having storm doors or leading into enclosed entryways. The FLOOR group consisted of the next two variables, (BASEMT) and (FLOOR). The former represents the presence or absence of a basement and the latter is the computed R value of flooring materials. The (SIZE) and (AGE) of the house and the presence of a fire place (FIREPL) or a heated (GARAGE) represented heat loss due to INFILTRATION.

To this expression two additional factors have been included. First, a number of variables describing the household size and age composition, which is also likely to affect the level at which desired home heating is achieved, have been added to the equation. Second, while homes heated with gas use the fuel primarily for space heating they may also have a hot water heater, stove, or clothes dryer which use the same fuel. 18/ The presence of these appliances will affect the absolute level of fuel required, except to the extent that they provide retained heat themselves.

In estimating the equation, there may be two problems. First, as the number of possibly important variables may be very large in comparison to the total number of household observations, degrees of freedom may be a problem. In addition, there may be a lack of sample variability. One solution is to

17/ The R value indicates the level of thermal resistance.

18/ Even if a household has all three appliances using the same fuel as that for heating, the gas consumed is generally no more than 25 percent of total gas use.

consider how households respond to changes over time. Large price changes in some fuels, national pressure to conserve during the embargo in 1973/74, and the threat of a natural gas shortage in 1976/77 may have caused households to make changes in the efficiency of their gas-heat transformation. As many of the structural factors describing heat retention will remain constant, as well as the age composition, the degrees of freedom problem can be avoided.

Three types of changes could be made. Recall that these changes were described previously. The first type are temporary changes, those affecting the actual transformation of gas to heat. The second type are structural adjustments -- changes in the heat retention characteristics of the house. The third type are changes in the stock of or utilization of the major appliances recorded.

Descriptive Results

Table 3 summarizes the extent to which the sample households reported making temporary adjustments in fuel-use in 1973/74 and how many households were still making those changes at the time of the survey, in Spring 1976. The five changes in daily routine incur no expense. LPG households made more temporary fuel-use in 1973/74 and how many households were still making those changes at the time of the survey, in Spring 1976. The five changes in daily routine incur no expense. LPG households made more temporary changes in 1973/74, on average, than households using NG. The largest differences were in response to questions about closing unused rooms, a change in the heat retention characteristics of the house, and lowering the hot water temperature, an adjustment in appliance use. Further, LPG households were not only more persistent in maintaining their new habits but in four of the five categories, more households had begun making those changes by Spring, 1976. For NG users there was no increase by 1976 and the percentage of reporting households decreased in two of the five categories. From these data, it appears that NG households did respond to the national pressure to conserve energy in 1973/74, but without a continuing price incentive, they were less determined than the LPG households to maintain these changes in their fuel-use habits.

This possibility leads one to question whether NG households which reported a change actually changed to the extent that an LPG household did. 19/ As heating is the major use of gas by all these households, the first three temporary changes could be expected to have the most impact on fuel-use efficiency. In closing off a room the action is clearly defined, and many more LPG households reported taking this action. Lowering thermostats, however, is not well-defined. The effect of turning down a thermostat depends on how much the temperature was

19/ There may also be survey bias where people indicated they made changes because they felt they ought to have made them.

lowered. 20/ The extent to which thermostats were turned down, in degrees lowered, provided some measure of the extent of this adjustment in habits, though these responses may also be biased. These data are reported in table 4.

For both the day and the night adjustment, more LPG-fueled households made larger adjustments of six or more degrees. Thus, while the same percentages of households reported turning down their thermostats, LPG households made more significant reductions.

Structural changes are adjustments in the heat characteristics of the house. While they require one to spend time or money, they are not necessarily permanent. For instance, caulking windows may need to be repeated periodically. Clearly, they are not all equally effective in increasing efficiency, but they all require more than a change of daily routines. Table 5 lists the structural changes and summarizes the data on households reporting making these changes during three heating years.

Table 3--Temporary Changes Reported by Households

Item	Households making change: 1973/74		Households still making change Spring, 1976	
	Percent			
	NG	LPG	NG	LPG
Fuel heat transformation				
Turned down thermostat for daytime	62.9	62.8	55.1	65.1
Turned down thermostat for nighttime	53.9	57.4	53.9	58.9
Heat retention characteristics				
Closed off unused rooms	38.2	46.5	34.8	47.3
Appliance use				
Turned down temperature on hot water heater	12.4	19.4	12.4	19.4
Used less hot water	39.3	34.1	33.7	27.9

20/ Further, households that lowered both day and night thermostat readings might well obtain a greater efficiency response than households that lowered the thermostat for only day or night.

These data show that few households in either group made structural changes in 1973/74 when LPG prices made their tremendous jump. 21/ Consumers were either unwilling to make substantial investments in energy savings in the short-term, or felt the "crisis" was only temporary, so adjustments in habits were adequate. National pressure to conserve energy moved few people to invest immediately in efficiency-related improvements for their homes. This was true even for LPG households which also faced substantial price increases. Further, because of lags in billing (since LPG households were only billed when their tanks were filled) it is probable that the extent of the price increases was not felt immediately after the rise.

By the 1974/75 heating year, however, marked differences in response occurred between the NG and LPG households. Many more LPG households reported making structural changes. This dichotomy was even more pronounced in 1975/76. LPG households reported continuing to make structural changes, yet despite the 25 percent price increase in April 1975, NG households reported little response. Given the relatively low price level for natural gas, the price rise was apparently too small to promote a large response in the short-run. Recall from

Table 4--Differences in Thermostat Adjustments

Amount thermostats were adjusted	Households that adjusted thermostats			
	NG		LPG	
	No.	Pct.	No.	Pct.
Day				
Households	56		81	
2-3 degrees		28.6		33.3
4-5		53.6		40.7
6-10		14.3		24.7
more than 10		3.6		1.2
Night				
Households	47		74	
2-3 degrees		23.4		35.1
4-5		55.3		36.5
6-10		19.1		23.0
more than 10		2.1		5.4

21/ Of the eight reported changes made by NG households in 1973/74, seven changes were made by one household.

figure 2 that while LPG prices did not remain at their 1973/74 peaks, they averaged in 1974/75 well over 50 percent higher than prices in earlier periods. So, by 1974, LPG households appeared to have decided that the price increases were real and took several measures to increase the fuel-use efficiency of their homes. The two most frequently reported improvements were caulking windows and increasing attic insulation.

The results of this survey show that people are willing to adjust their fuel-use habits in both the short and the long run. They also show that a substantial economic incentive is required to create a significant response. While the first responses were temporary, structural changes did follow when the price of fuel remained relatively high.

Regression Results

The regressions to follow will indicate whether the changes households made are statistically important in explaining the changes in actual fuel use. The equation for the change in fuel use over time is given below:

$$\Delta K_j = a + b_1 \Delta ATTICINS_j + b_2 \Delta WALLINS_j + b_3 \Delta STORMDR_j +$$
$$b_4 \Delta WINDOW_j + b_5 \Delta SIDING_j + b_6 CAULKING_j + b_7 WEASTRIP_j +$$
$$b_8 DAYCHG_j + b_9 NITECHG_j + b_{10} CLOSERMS_j + b_{11} HWHTEMP_j +$$
$$b_{12} LESSHW_j + b_{13} ADDAPP_j + b_{14} DROPAPP_j + e \qquad (7)$$

The functional form of this equation is also linear. Again, the dependent variable may take two forms. The first, ΔK is defined as $K_{t+1} - K_t$, fuel-use efficiency in one year minus that of the previous year. The second, ΔF is the difference in the actual amount of fuel consumed from one year to the next.

Table 5--Structural Changes Reported by Households

Changes	1973/74		1974/75		1975/76	
	NG	LPG	NG	LPG	NG	LPG
			Percent			
Add attic insulation	1.1	2.3	2.2	11.6	0	7.0
Add wall insulation	1.1	0	3.4	2.3	0	5.4
Add storm windows	1.1	0.8	5.6	2.3	0	5.4
Add storm doors	0	0.8	1.1	5.4	0	3.1
Cover windows with plastic	2.2	3.1	2.2	1.6	2.2	2.3
Caulk windows	1.1	3.9	5.6	11.6	6.7	7.0
Cover window air conditioner	0	2.3	1.1	3.9	0	1.6
Weatherstrip	1.1	0.8	1.1	3.1	1.1	4.7

Since this variable does not control for climate, an independent variable which takes the changes in the weather into account could be used.

The explanatory variables are grouped into the three categories of changes described above: structural, temporary, and appliance. The first seven variables are physical improvements in the structural characteristics of the house in order to reduce heat loss. They are the addition of attic (ΔATTICINS) and wall (ΔWALLINS) insulation, the installation of storm doors (ΔSTORM-DR), windows (ΔWINDOW), and siding (ΔSIDING), and the use of (CAULKING) and weatherstripping (WEASTRIP). The next five variables are temporary and require a change in the behavior of household members. (DAYCHG) and (NITECHG) record, in degrees, the extent to which the thermostat is lowered during the day and night, respectively. (CLOSERMS) indicates whether unused rooms are closed off to reduce the total heated area. Reducing the amount of hot water used (LESSHW) is probably the hardest adjustment to maintain while lowering the temperature of the hot water heater (HWHTEMP) is the simplest. The final two variables indicate the addition (ADDAPP) or elimination (DROP-APP) of the three major appliances which may use NG or LPG.

Three NG and three LPG cross-section regression equations were estimated separately using both the K value and the F value as the dependent variable. Only the final fuel-use equations are presented here. 22/ Recall that engineering estimates generally show a linear relationship between fuel use and degree days. Such a relationship is represented more nearly by using actual fuel use as the dependent variable. Table 6 shows the results of estimating the final NG equation. Only the briefest summary of these results is provided below.

NG households, since they receive the gas via transmission line, are metered and billed monthly by the utility. There is no variation in cumulative degree days among the NG households and its effect must be picked up by the constant term. Ten of the 17 explanatory variables were significant at the 10 percent level. The results of the NG estimations indicate that characteristics in six of the eight originally defined categories of important fuel use variables did, in fact, contribute to the variation in fuel use across the NG sample and together they explained about half of its variation. Of these variables, the number of doors and stories and the presence of a heated basement were consistent energy users. The number of adults in the home and the presence of a hot water heater or dryer also contributed to fuel consumption across the sample. On the other hand, wall insulation, storm doors, and the presence of a porch acted as energy conserving factors.

22/ In some cases variables were modified to better explain behavior.

LPG is delivered by truck to private tanks at each house. The deliveries are irregular, depending on the size of the tank and the rate at which LPG is used. However, using the records of fuel deliveries, LPG consumption by each household has been fit, as well as possible, to the heating year. Since the calculated length of each household's heating year is slightly different, the LPG data require the addition of a variable (DDCUM) which records the total number of degree days accumulated in the heating year. The results of estimating the final LPG equation are shown in table 7.

Seven of the eight categories contributed to explaining the variation in energy use. The size of the household was important in determining fuel use as were the number of stories and the presence of a basement or garage which enlarged the total heated area. The fireplace certainly increased fuel use through the loss of heat up the chimney. Auburn University researchers found that using a fireplace regularly can raise a

Table 6--Cross-Section Analysis of Natural Gas Fuel Use

Variable	1972/73	1973/74	1974/75	1975/76
Constant	987.04	443.98	190.16	363.27
ATTIC	127.34 (0.84)	180.72 (1.38)	164.94 (1.16)	181.99 (1.45)
ATTICINS2	-131.87 (0.82)	-110.19 (0.79)	-181.57 (1.17)	-171.61 (1.24)
WINDOW	-167.25 (1.07)	-30.50 (0.23)	94.21 (0.54)	-20.22 (0.12)
WALLINS	-55.95 (1.56)	-44.91 (1.44)	-45.85 (1.35)	-38.96 (1.30)
STORIES	449.61 (3.38)	375.74 (3.26)	386.50 (3.03)	425.04 (3.81)
PORCH	-128.66 (1.37)	-125.31 (1.54)	-124.54 (1.39)	-102.91 (1.31)
DOORS	97.06 (1.22)	141.33 (2.05)	175.38 (2.31)	125.66 (1.87)
STORMDR	-3.00 (1.39)	-2.20 (1.18)	-2.43 (1.21)	-2.01 (1.13)
BASEMT	238.92 (1.68)	163.85 (1.32	215.36 (1.58)	161.47 (1.33)
SIZE	0.04 (0.35)	-0.00 (0.04)	0.01 (0.14)	0.01 (0.08)
FPOOOR	192.29 (0.46)	205.29 (0.56)	271.75 (0.67)	257.14 (0.72)
ADULTS	139.39 (1.14)	189.90 (1.79)	223.20 (1.93)	205.41 (2.01)
CHILDREN	-0.45 (0.19)	0.61 (0.29)	0.29 (0.13)	1.19 (0.57)
INCOME	-0.30 (0.01)	-12.85 (0.45)	-16.78 (0.54)	-9.80 (0.36)
HWH	361.96 (2.22)	389.43 (2.74)	450.57 (2.92)	349.30 (2.57)
DRYER	250.79 (1.68)	232.61 (1.78)	198.94 (1.40)	193.77 (1.55)
STOVE	-7.66 (0.05)	-72.21 (0.50)	-28.77 (0.18)	-54.72 (0.40)
—				

Values in parentheses are t-statistics

monthly heating bill by about twenty percent. 23/ Finally the presence of an LPG-fueled hot water heater and dryer contributed to fuel use, while attic and wall insulation, and storm doors, were important energy conservers.

The time-series equations for the NG and LPG households are shown in table 8. The following interpretations are suggested, based on the results of these regressions. LPG households responded during the year of the OPEC embargo,

Table 7—Cross-Section Analysis of Liquefied Petroleum Fuel Use

Variable	1972/73	1973/74	1974/75	1975/76
Constant	-703.03	-495.69	-422.52	761.01
DDCUM	0.27 (6.71)	0.23 (4.78)	0.23 (4.83)	0.10 (2.22)
ATTIC	-9.88 (0.11)	-44.81 (0.46)	-39.33 (0.43)	-7.16 (0.07)
ATTICINS	-36.79 (2.24)	-15.43 (0.87)	-14.47 (0.88)	3.19 (0.18)
WINDOW	-11.36 (0.11)	-22.45 (0.19)	-15.82 (0.13)	-250.12 (1.28)
CURTAINS	11.67 (0.37)	0.74 (0.01)	-60.85 (0.53)	-51.15 (0.39)
SIDING	-0.03 (0.02)	-0.96 (0.68)	-0.85 (0.64)	-1.08 (0.72)
WALLINS2	-123.13 (1.22)	-338.37 (3.10)	-243.71 (2.34)	-207.59 (1.82)
STORIES	227.31 (2.63)	240.96 (2.58)	220.09 (2.47)	212.80 (2.22)
DOORS	-24.38 (0.55)	-30.06 (0.62)	-12.07 (0.26)	20.34 (0.40)
STORMDR	-1.09 (0.79)	-1.56 (1.04)	-2.26 (1.59)	-0.77 (0.50)
BASEMT	137.92 (1.67)	149.02 (1.67)	160.52 (1.95)	69.29 (0.77)
SIZE	0.23 (3.30)	0.18 (2.35)	0.17 (2.50)	0.08 (1.00)
FIREPLACE	313.38 (3.01)	258.95 (2.29)	280.02 (2.65)	256.08 (2.25)
GARAGE	399.01 (3.47)	457.87 (3.83)	380.79 (3.40)	346.84 (2.78)
ADULTS	62.75 (0.83)	140.17 (1.72)	93.63 (1.22)	36.12 (0.43)
CHILDREN	1.78 (1.13)	-0.46 (0.27)	-1.25 (0.78)	-0.96 (0.53)
INCOME	-12.85 (0.61)	-7.78 (0.34)	-5.32 (0.26)	16.16 (0.69)
HWH	107.52 (1.35)	173.58 (1.97)	152.76 (1.84)	62.37 (0.68)
DRYER	149.47 (1.51)	148.12 (1.41)	62.26 (0.63)	-96.42 (0.89)
STOVE	6.93 (0.08)	74.66 (0.81)	[illegible] ([illegible].01)	108.72 (1.15)
$R^2/\bar{R}^2$	.56/.48	.48/.38	.46/.36	.38/.26

Values in parentheses are t-statistics

23/ Ingrassia, Paul "Guess What Wastes Lots of Hot Energy in the Living Room", Wall Street Journal, December 30, 1977. Our figures suggest that the mere presence of a fireplace increased fuel use by 16.6 percent.

Table 8--Changes for both LPG and NG users in Fuel Use Over the Time Periods

Variable	73/74 - 72/73	74/75 - 73/74	75/76 - 74/75	75/76 - 72/73
<u>LPG</u>				
Constant	-42.83	-78.50	-15.43	-67.62
DDCHG	0.23 (15.51)	0.18 (13.87)	0.16 (11.56)	0.21 (10.95)
DAYCHG	-19.88 (2.15)	-0.86 (0.14)	4.49 (0.61)	-15.91 (1.35)
NITECHG	-9.86 (1.31)	8.47 (1.50)	-3.28 (0.49)	-11.66 (1.14)
LESSHW	69.55 (1.20)	-42.12 (1.01)	7.31 (0.17)	38.87 (0.56)
CLOSERMS	-54.34 (1.16)	31.29 (0.96)	-50.25 (1.35)	19.34 (0.33)
HWHTEMP	-21.23 (0.27)	15.17 (0.30)	89.56 (1.60)	69.09 (0.81)
CAULKING	-218.33 (1.24)	-112.18 (1.90)	-22.32 (0.28)	-157.80 (1.93)
WEASTRIP	471.34 (1.94)	67.33 (0.60)	254.77 (2.82)	-108.68 (1.04)
ΔATTICINS	-53.40 (0.64)	11.41 (0.82)	-24.59 (1.35)	-6.01 (0.29)
ΔWALLINS	--	-54.22 (1.74)	-71.18 (2.37)	-97.87 (2.70)
ΔWINDOW	31.75 (0.14)	23.37 (0.24)	79.83 (1.16)	-16.13 (0.19)
ΔSTORMDR	116.86 (0.49)	-35.92 (0.49)	-37.35 (0.33)	65.05 (0.62)
$R^2/\overline{R}^2$	.75/.72	.74/.71	.66/.62	.63/.59
<u>NG</u>				
Constant	-166.11	160.18	-151.35	155.08
DAYCHG	-9.99 (1.14)	-13.22 (1.75)	2.80 (0.43)	-21.22 (1.74)
NITECHG	-2.83 (0.47)	5.99 (1.18)	-3.86 (0.90)	-0.41 (0.05)
LESSHW	-6.68 (0.13)	-30.06 (0.64)	0.91 (0.02)	-73.05 (0.96)
CLOSERMS	-11.68 (0.25)	-5.54 (0.14)	-21.90 (0.68)	-9.25 (0.15)
HWHTEMP	76.62 (0.97)	-74.21 (1.14)	-11.76 (0.22)	-35.15 (0.34)
CAULKING	461.41 (1.54)	-14.71 (0.18)	-27.53 (0.40)	165.58 (1.71)
WEASTRIP	184.14 (0.90)	--	77.90 (0.49)	106.31 (0.37)
ΔATTICINS	115.35 (1.54)	-39.84 (1.05)	--	6.83 (0.14)
ΔWALLINS	--	--		-79.49 (2.01)
ΔWINDOW	-215.48 (1.00)	76.84 (0.86)	36.78 (0.35)	-24.86 (0.22)
ΔSTORMDR	--	15.81 (0.08)	--	-435.14 (1.08)
$R^2/\overline{R}^2$	.07/--	.10/--	.02/--	.15/.03

Values in parentheses are t-statistics.

1973/74 by lowering the thermostat settings, both during the daytime and at night. These changes are costless though they require reasonable motivation since they entail daily changes in habit. Another measure, weatherstripping, was also significant but its coefficient was positive. This result suggests that either it was not effective or more likely, the households did not actually implement or maintain the changes to the extent that they had indicated. No major structural changes were undertaken in the short run.

In the following two years, as prices remained high, several LPG households undertook structural changes of adding attic and wall insulation. Caulking and weatherstripping were also effective after the first year in reducing fuel use. With the exception of closing off spare rooms, the temporary changes were never significant, suggesting either that household members did not believe these changes in habit were effective or that the households were less attentive to the daily requirements of the temporary changes. That is, there may well be a significant survey bias in the responses to these questions where families respond that they made the adjustments but they were not actually adjusting every day.

The trend in the use and effectiveness of conservation measures over time suggests clearly that LPG households responded to the surge in their fuel prices (and possibly to the national campaigns to conserve). They implemented low cost conservation measures in the short run and more costly, though also more permanent, measures over time when it became clear that fuel prices were not going to return to their 1972/73 levels.

On the other hand, natural gas households traditionally faced lower fuel prices and, in addition, they did not face price increases as a result of the OPEC embargo. Any changes made in their fuel-use behavior might be attributable to their response to the government's campaign to encourage households to conserve energy. Such an incentive did not convince NG households to try to use less fuel in 1973/74. In the following year, however, NG households did reduce daytime thermostat settings. Comparing fuel use between 1975/76 and 1972/73, the installation of wall insulation also had the expected negative sign. Once again, the temporary changes were ineffective forms of fuel-use conservation. These results suggest that NG households felt little incentive to respond to the OPEC embargo in the short run, but did eventually show some response to the energy conservation campaign and to the subsequent, if slow, increases in NG prices.

SUMMARY

The objective of this study was to measure the factors affecting residential fuel use and to compare the willingness of two groups of consumers to adjust to very different changes in their heating costs over similar periods of time. Even before the OPEC embargo, LPG households used fuel more efficiently than their NG counterparts. Their higher K values were not due to differences in the characteristics of the housing stock but to differences in the long-run responses of the two sets of households to fuel prices. LPG-fueled households faced traditionally higher gas prices. In the three year period after the embargo, differences in the changes in fuel-use efficiency over time between NG and LPG households can be explained by comparing their levels of adoption of energy conservation measures. LPG households reported making more and bigger temporary changes than NG households and were more persistent in maintaining their new behavior. LPG households also invested in major structural improvements to the heat resistance of their homes while few NG households were so motivated. In response to the disagreement about whether people are willing and able to alter their fuel use, it appears that people can indeed adjust their fuel-use habits in the short and long-run, but a substantial economic incentive is required to create a significant, and sustained, response. In the absence of a price incentive, appeals to the national conscience and exhortations to voluntary conservation did not succeed.

The study examined the roles of various structural characteristics of the houses as well as socio-economic influences in determining fuel consumption within the homes. The analytic framework was derived from the household production function approach to demand modelling. In this approach the household combines inputs in a production process to produce the commodities desired and from which their utility is derived. While heating fuel is the primary market good in residential space heating, engineers believe many of the structural characteristics of the house affect the amount of fuel needed to maintain a desired level of heating. The household production function approach provides a way to include important structural characteristics of the house into the estimation. The household's demand for fuel was shown to be a derived input demand, a function of these structural characteristics, as well as the more traditional variables. Unfortunately, due to the lack of cross-sectional variation in prices, the basic estimating equation was reduced to one which explained fuel use as a function of a set of six categories of structural variables, a number of socio-economic factors, and information about the presence of gas-fueled appliances.

The results of the cross-section regression estimations indicated that characteristics in most of the structural and socio-economic categories contributed to the variation in fuel use. The limited nature of the survey data no doubt caused important structural variables to be unrepresented and others to be poorly specified. However, about half the cross-sectional variation in fuel use was explained. This suggests that the use of a system which allows the inclusion of important

structural variables of the house in the estimation provides a most satisfactory explanation of fuel use variation across households.

Regression equations were also estimated for differences across households in fuel use over time. For the LPG households, fully three-fourths of the variation was explained in the years following the OPEC embargo. A large part of the explanation of changes in LPG consumption was, no doubt, captured by the change in degree day variable, (DDCHG), which could not be included in the NG equations. The trend in the use and effectiveness of conservation measures over time suggests clearly that LPG households responded to the surge in their fuel prices by adopting no-cost conservation strategies in the short-run. Over time, more costly, though more permanent measures were also implemented. The prices faced by NG households were traditionally lower than those for LPG-fueled households and did not increase as a result of the OPEC embargo. Consequently, NG households felt little incentive to conserve.

Although Gronau stated that "the household production function is now an established part of economic theory", this study is certainly one of the first applications of this methodology to estimate demand using an actual production function. 24/ The general success of the production function approach here suggests its broader applicability to similar problems.

24/ Gronau, Reuben, "Leisure, Home Production and Work -- The Theory of the Allocation of Time Revisited", Journal of Political Economy, Volume 86, Number 6, December, 1977.

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